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# COMPARATIVE ANALYSIS OF PRODUCTION FLOW SCENARIOS IN TYPOGRAPHIC INDUSTRY

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***Abstract:*** *The paper presents the comparative analysis of a production flow of a flexographic typography by analysing the possibilities of reducing auxiliary times in order to make the process of obtaining printed products more efficient. Two work scenarios were studied, involving the printing of four products obtained in the same production line, with different processing times and auxiliary times for each. In Scenario 1 the independent printing of each product was carried out, and in Scenario 2 the methods FIFO, Line Balance and Minim Setup were applied. Scenario 1 resulted in a maximum machine occupancy time with the four products, and Scenario 2 resulted in 24 product series variants with four values of machine occupancy time, as follows: minimum value, maximum value and two intermediate values. The applied techniques allowed the identification of the best variant but also the identification of the facilities offered by the system through the components of the printing and flexographic die cutting groups, in order to reduce the auxiliary times respectively the constraints, grouping the printing of the products in a pre-determined order.*

***Key words:*** *flexographic production, production flow, scenarios, process time, analysis.*

## 1. INTRODUCTION

The paper aims to study the ways and possibilities of streamlining the flexographic production process [1, 2], by minimising the time spent in the successive stages of obtaining products printed by flexographic technology.

On the background of the complexity of flexographic printing due to the multitude of elements that intervenes throughout the production flow, it is necessary to prioritise the products that go to print so that there is an optimal run time [3].

To that end, the comparative analysis is applied in this paper to determine and eliminate or reduce constraints due to the need to deliver a series of products to a single customer as quickly as possible [4, 5], or constraints [6] related to the need to change the order of delivery of orders in a period of 24 hours.

Thus, the need arises at the decision-making level to choose the optimal order of entry of products into the production run that satisfies the requirement of minimum execution time of a series of products requested at the same time at delivery or the minimum execution time requirement for delivery in a certain sequence of the products. Methods such as FIFO (first input, first output), Line Balance and Minim Setup were applied.

Identifying the elements that can help reduce auxiliary times and how to use them predictably in production can bring consistent improvements to the production process. In this respect, modelling production flows using modern evaluation software [7, 8] can reveal the best production options.

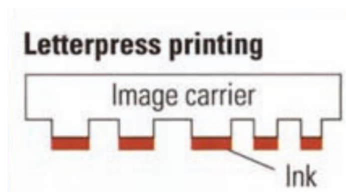


**Fig. 1.** Letterpress printing: the working principle of flexographic printing [2].

Flexography or flexographic printing is a letterpress printing (Fig. 1) whose particularity consists in the use of flexible plates (called *clichés*) for printing on the printing substrate [2].

Flexographic technology usually produces finished products in rolls: labels, folding products, flexible packaging (foils) and continuous bands.

The flexographic printing machine (Fig. 2), through its own specific equipment, given by the manufacturer from the construction, intervenes directly in the printing process to obtain the semi-finished product, through the following major components: printing units and die cutting units [9].

## 2. CURRENT STATUS

One of the important events in a typography is the production planning of the products in such a way that all the necessary machinery is used to the maximum for the execution of the product and all the auxiliary devices involved in the technological process are used efficiently in order to optimise the production line [10].

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**Fig. 2.** Flexographic press used for printing with 8 printing units [9].

The specific organisation of a flexographic printing workflow includes the following successive steps:

- *Print production*: products are flexographic printed according to the customer's requirements and noted in the Technological Sheet. Production consists of feeding the machine with rolls of raw material and printing / die cutting the product according to the Technological Sheet, using consumables and parts required for production, to achieve the print run requested by the customer.
- *Print finishing*: finishing operations are carried out in line with the print and consist of finishing the product by: varnishing, laminating, silkscreen printing, die cutting and serial number printing. The type of finishing to be applied is specified in the Technological Sheet.
- *Finishing the product*: with very few exceptions, the printed rolls are transferred from the printing machine to the machine dedicated to longitudinal cutting, called slitter, where the finishing operations consist of slitting and rewinding the rolls to finished dimensions.
- *Packaging and product marking*: packaging is specific to each product category and can be: wrapping with strech foil, packing in boxes or direct fixing on europallets. Each roll or stack of finished product is marked with an identification label.
- *Delivery or storage of products*: once packaged, finished products are delivered immediately or are stored in a short-term holding area, depending on delivery times.

It can be seen that the first three stages involve the use of machinery, as follows: the production and finishing of the print is carried out on the printing machine and the finishing of the product on the slitter. Packaging and marking of the products is done at the slitter workstation, after each set of rolls finished on the machine.

Thus, for the comparative analysis of the production of flexographic prints, the structure of a flexographic printing process can be can be assimilated to a dynamic, stochastic and discrete model, composed of three structural parts: Printing – Finishing – Delivery, where the time consuming parts of the production run are printing and finishing processes.

Representing the process in this way [11], allows a simple graphical representation of the complex flexographic printing process. Thus, in the Printing process (Fig. 3), three types of products information's are fed into the system:

- *verifiable input*: these are the elements necessary to prepare the production at START 0, respectively the order to launch the product into production, the Technological Sheet specific to each product; raw material: printing substrate, tubes for running the product, inks and varnishes for printing, boxes and europallets for packaging; clichés / die cut: these are parts necessary for printing and die cutting respectively; proof or first print sample: these are parts necessary for quality inspection of the printing.
- *uncontrollable input*: these are those given by discrete events: washing of clichés, aniloxes and ink tanks, mounting and dismounting of clichés, die-holder cylinders and die cut.
- *output*: these are printed semi-finished rolls of a width comprising a given number of rows of labels.

In the Finishing process (Fig. 4), the three types of products information's sent to the system are:

- *verifiable input*: these are the semi-finished rolls, the Technological Sheet of product, tubes, labels with product identification data, and the consumables needed for packaging: boxes, strech foils, europallets, package identification labels;
- *uncontrollable input*: are unpredictable changes in the direction of the finished roll or in the size (number of labels per roll), the latter involving changes in the packaging mode;
- *output*: these are products packed in boxes or packed by direct wrapping on europallets.

## 3. CASE STUDY

For the case study, the model was designed for an existing physical system, as follows: the first four products, noted P1, P2, P3, P4, belonging to a single type of flexographic printing machine, symbolically noted Machine 1, were chosen in the order of receipt of repetitive orders.

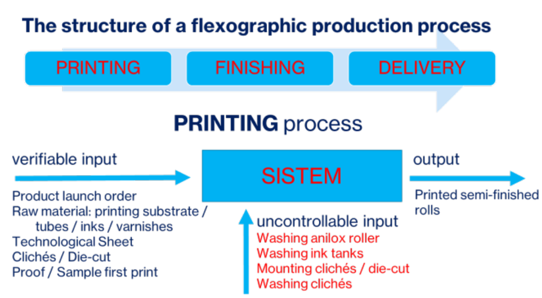


**Fig. 3.** Types of products information's in a print process.

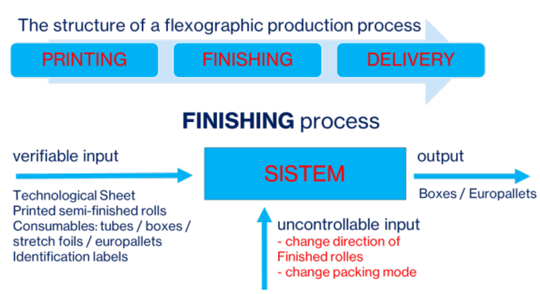


**Fig. 4.** Types of products information's in a finishing process.

*Table 1*

**Parameters of printed flexographic products**

| Products | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| *L* [m] – length of printed material | 18,000 | 25,000 | 22,100 | 5,100 |
| Inks used | Cyan + Magenta + Yellow + Black + Blue + Varnish | Green | Black + Red + Violet | back printing: Cyan + Black |
| *n* [-] – number of printing groups | 6 | 1 | 3 | 8 |
| *D* [mm] – diameter of the die cut-holder cylinder | 171.81 | 194.04 | 198.08 | 194.04 |
| Die cut product | no | yes | yes | yes |

The distinctive aspects of the four products are:

- P1 is a foil printed product and does not require die cutting; it is used as flexible packaging;
- P2 is a TAG – a non-adhesive label with a signalling or marking role; it contains cross perforations with a folding / tearing role;
- P3 is a self-adhesive label, designed for application on recipient packaging;
- P4 is a ticket printed on both sides on cardboard and is intended for cultural activities.

The four products were analysed in terms of graphics, the possibility of printing and die cutting by using the flexographic process. The production parameters are presented in Table 1.

The die cut-holder cylinder is the piece where the die cut for cutting the product is mounted. The cliche-holder cylinder is the piece where the cliché for printing the graphics is mounted.

Cyan, Magenta, Yellow, Black inks are referred to as polychrome inks and Blue, Green, Red, Violet, Orange are referred to as Pantone® special colours [12].

As the product P1 is a continuous printed film, only the products P2, P3 and P4 require die cutting, which consists of contour cutting for P3 and tear perforations for P2 and P4.

The length of raw material rolls for all four types of material is $L_{roll}$ = 5,000 m. For each print run an integer number $N_r$ of raw material rolls is used, example: for product P4 the print run is 5,100 m, 2 rolls of raw material are used, of which 4,900 m will remain unused. The calculation formula for $N_r$ is:

$$N_r = L / L_{roll} \text{ [no of rolls]} \quad (1)$$

and the decimal result is rounded up to the first integer value.

### 3.1. Process structure

Figure 5 shows the study approach for comparative analysis of the flexographic technology flow using the FIFO method, applicable to the case study, in which the

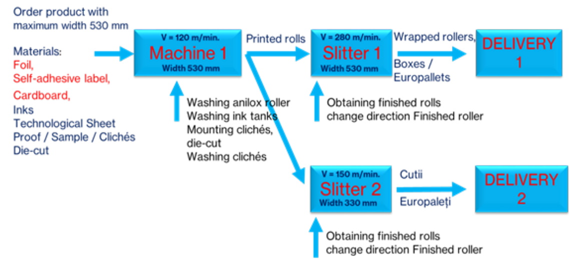


**Fig. 5.** Representation of input and output products information's in the process flow diagram for existing physical system.

input and output product information's of the system are represented by horizontal arrows and the vertical arrows represent the support mechanisms of the system functions.

The input product information's also includes the customer's requirements for the type of substrate (foil, self-adhesive label, cardboard), the total length of printed material, the finishing of the product in rolls or stacks, the number of labels per finished roll and the number of labels per fold for products delivered in stacks.

The flexographic press used is equipped with 8 printing units with the possibility of printing in 8 colours or 7 colours + 1 varnish, and a die cutting unit. The maximum width of material that can be printed on this machine is 530 mm and the printing speed is 120 m/min.

In this case study, after printing / die cutting on the flexographic machine, rolls are obtained with the semi-finished products. These rolls are transferred to two slitters with the following characteristics:

- Slitter 1 that can process rolls with a maximum width of 530 mm at a speed of 280 m/min;
- Slitter 2 that can process rolls up to 330 mm wide at a speed of 150 m/min.

Since the working speed of the two slitters is higher than the printing speed of the flexographic machine, and the printed products are immediately picked up for finishing at the two slitters, the subject of the paper focused on the comparative analysis of the production on the printing machine only, since neither of the slitters influences what happens on the flow.

### 3.2. Production flow and work phases.

After preparing the START 0 moment, the production flow to be followed by each product is precisely established.

In Fig. 6 are the components of the production flow numbered in the order of the sequence of the work phases, according to the machines involved and the stationary and delivery stations, as follows: G1 – G12 are the working groups at the flexographic printing machine; WA1 is the waiting area numbered 1 of the semi-finished rolls coming out of the printing machine, before being transferred to the slitter S; S1 is the station for feeding the slitter with semi-finished rolls; S2 is the station for adjusting the knives at the slitter for cutting the semi-finished rolls into finished rolls; S3 is the station for gluing the roll ends with identification labels, at each set of rolls completed at the slitter; S4 is the station for finishing the entire run at the slitter, with direct packaging

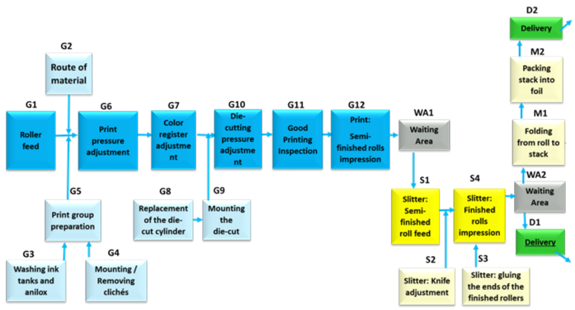


**Fig. 6.** Active components in the production flow and ordering of work phases.

of the finished rolls; WA2 is the waiting area numbered 2 for the packaged products before transferring them to delivery station D1, or, as the case may be, transferring them to manual work station M1 for folding the finished rolls into stacks; M2 is the station for wrapping each stack with strech film and packaging them in boxes, after which they are transferred to delivery station D2.

### 3.3. Establishing process times

In the case study all products are produced on the same production line with different processing times and auxiliary times for each. Thus, the times for each printing press workgroup G were measured experimentally on a flexographic system and have the values in Table 2.

*The preparation time for loading / unloading rolls and arranging the material path through the machine* is related to groups G1 and G2 and comprises work at the two ends of the machine: at one end the machine is fed with the roll of raw material, preceded by the removal of the end of the roll already in use; at the other end of the machine the roll of semi-finished product is removed, placed in the transit area, and prepared for a new roll by feeding the tube onto the rewinder spindle and fixing the web of material onto the tube.

Also at this stage, the material path through the machine is arranged: in flexography, products printed on both sides require a special material path through the machine in order to be printed on the back, so the next time the product goes to press, this path must be repeated, but only when there are not enough printing units.

In the case study, products P1, P2 and P3, do not require re-pathing after printing product P4 printed on both sides, regardless of the order in which they go to press, instead time is consumed in preparing the material path for printing product P4.

This time is denoted by $t_{MP}$ and the calculation formulae are as follows:

- for printing the product only on the face of the material:

$$t_{MP} = N_r \cdot t_{G1}, \quad (2)$$

- for printing the product on the front and back of the material:

$$t_{MP} = (N_r \cdot t_{G1}) + t_{G2}, \quad (3)$$

where $N_r$ is the number of rolls of raw material and is calculated with Eq. (1).

*The printing unit preparation time* is related to the G3, G4 and G5 units and includes the following steps: washing the ink tanks and anilox rollers, choosing the anilox roller and fixing it in the unit, mounting the doctor blade holder, filling the ink tank and fixing the ink unit in the machine at the workstation given by the colour printing order. Mount all the clichés on the cliché-holder cylinder, then fix them in the corresponding printing units. Each printing unit has a colour unit comprising an ink tank with an anilox, and a cliché mounted on a cliché-holder cylinder. Each product has as many printing units as the number of colours required for printing.

This time is denoted by $t_T$ and the calculation formula is as follows:

$$t_T = n \cdot (t_{G3} + t_{G4} + t_{G5}), \quad (4)$$

where $n$ is the number of printing groups for the product and has the values in Table 1.

*The run time for the print adjustment* is related to the G6 and G7 groups and includes matching the pressures for optimal printing of the inks on the printing substrate, is performed for each ink group, and is followed by the semi-automatic adjustment of the colour register, respectively the precise and simultaneous overlapping of all colours to ensure a clear reproduction of the graphics. This time is denoted by $t_{RT}$ and the calculation formula is as follows:

$$t_{RT} = (n \cdot t_{G6}) + t_{G7}, \quad (5)$$

where $n$ is the number of printing groups for the product and has the values in Table 1.

*Table 2*

**Process times in the working groups of printing machine**

| Working group | Preparation / execution times | | Duration [min] |
|---|---|---|---|
| G1 | Loading and unloading time 1 roll raw material | $t_{G1}$ | 10 |
| G2 | Material path set-up time through the machine, for back printing | $t_{G2}$ | 60 |
| G3 | Ink wash time 1 colour ink tank and 1 anilox | $t_{G3}$ | 15 |
| G4 | Assembly and disassembly time 1 clip | $t_{G4}$ | 5 |
| G5 | Preparation time printing group | $t_{G5}$ | 10 |
| G6 | Print pressure adjustment time 1 colour | $t_{G6}$ | 5 |
| G7 | Semi-automatic colour register adjustment time all groups | $t_{G7}$ | 6 |
| G8 | Die cut-holder cylinder change time | $t_{G8}$ | 50 |
| G9 | Mounting and dismounting die cut time | $t_{G9}$ | 10 |
| G10 | Adjustment time of the die cut pressures | $t_{RS}$ | 2 |
| G11 | Inspection Time for Pass for Press | $t_{BT}$ | 10 |
| G12 | Runtime for product Pi, where $i$ = 1 – 4 | $t_{Ri}$ *) | **) |
| | *) where $i$ = 1 – 4<br>**) values are: for P1, $t_{R1}$ = 150 min; for P2, $t_{R2}$ = 208 min; for P3, $t_{R3}$ = 184 min; for P4, $t_{R4}$ = 42.5 min. | | |

*The set-up time of the die cut assembly* is related to groups G8 and G9 and involves, for the products to be die cut, changing the die cut-holder cylinder from the previous job to the one for the current job and respectively removing the die cut from the previous job and fitting the die cut for the current job. This time has been noted with $t_S$ and the calculation formula is as follows:

$$t_S = t_{G8} + t_{G9}, \quad (6)$$

where the values for $t_S$ are as follows: $t_S$ = 60 min when the die cut-holder cylinder needs to be changed, and $t_S$ = 10 min when the die cut-holder cylinder does not need to be changed.

*The die cutting pressure adjustment runtime* is related to the G10 group and involves continuous clamping of the die cut in the die cutting group until a correct cut of the print substrate is achieved. This time is denoted by $t_{RS}$ and has the value given in Table 2.

*The inspection preparation time* for the Pass for Press is related to group G11 and involves checking the print quality of the substrate by comparing it with samples received from the customer or measuring the colours with specific flexographic printing equipment. When the quality conditions are met, the Pass for Press is granted which marks the start of the print run. This time is denoted by $t_{BT}$ and has the value given in Table 2.

*The print run time* is related to group G12 and depends on $L$ – the total length of material to be printed and $v$ – the printing speed of the flexographic machine. This time is denoted by $t_{Ri}$ where $i$ = 1 – 4 and is calculated individually for each product P1, P2, P3, P4 (Table 2) with the following calculation formula:

$$t_{Ri} = L / v, \quad (7)$$

where $L$ has the values in Table 1 for each product and $v$ = 120 m/min.

*The total execution time for each product Pi*, where $i$ = 1 – 4, is denoted by $t_{Pi}$ and calculated with the formula:

$$t_{Pi} = t_{MP} + t_T + t_{RT} + t_S + t_{RS} + t_{BT} + t_{Ri}. \quad (8)$$

*The machine occupancy time for each series of* 4 *products* is noted with $T$ series index. For example: for series P1-P2-P3-P4, the machine's occupancy time for the execution of this series is noted $T_{P1P2P3P4}$ and is calculated with the formula:

$$T_{series} = \sum t_{Pi}, \text{ where } i = 1 – 4. \quad (9)$$

In order to distinguish between the machine occupancy times for the execution of the series obtained in the two *Scenarios*, the index is preceded by the number 1 or 2 thus:

- for *Scenario* 1: $T_{1\_}$ series index; example: for *Scenario* 1 series P1-P2-P3-P4, the machine's occupancy time is noted $T_{1\_P1P2P3P4}$;
- for *Scenario* 2: $T_{2\_}$ series index; example: for *Scenario* 2 series P1-P2-P3-P4, the machine's occupancy time is noted $T_{2\_P1P2P3P4}$.

Thus, the formula (9) for calculating the machine occupancy time for running the series in *Scenario* 1 becomes:

$$T_{1\_series} = \sum t_{Pi}, \text{ where } i = 1 – 4 \quad (10)$$

and for the machine occupancy time for running a series in *Scenario* 2, Eq. (9) becomes:

$$T_{2\_series} = \sum t_{Pi}, \text{ where } i = 1 – 4. \quad (11)$$

To facilitate the analysis of the values obtained, the unit of measurement used for the calculation of the machine occupation times for the execution of the series of products was hours, the transformations from minutes to hours were calculated to four decimals and the results were rounded to one decimal.

### 3.4. Running the process in two scenarios

The following assumptions are considered:

- Production works in 3 shifts, 8 hours each, shifts start at 6, 2, 10 p.m. A shift lasts 15 minutes and a lunch break lasts 15 minutes.
- During all these times, the continuous operation of the machines is ensured, as follows: the shift change is done with the machine being taken over on the move, and meal breaks are taken at a staggered time so that during these times the machines have at least one worker supervising them at all times.
- The printing press works at full capacity, without variations, there are no breakdowns while printing runs and all the material on the press is printed.

For printing process running, the analysis of the auxiliary times and the comparative study, two working scenarios [13] were chosen, as follows:

- *Scenario* 1, in which each product is printed independently, where for each product all ink tanks are prepared and for each die cut product the die cut-holder cylinder is installed.
- *Scenario* 2, in which the products are successively printed in series according to the FIFO strategy. To obtain the series, different combinations of the four types of products are applied to the printing input, obtained by permutations P1-P2-P3-P4; P1-P2-P4-P3; P1-P4-P3-P2; [...] P4-P2-P3-P1, resulting in a total of 24 product series.

The input and output parameters in running the process in the two scenarios are the set-up and run times at the printing press workgroups G1…G12 (Fig. 7) and are calculated with Eqs. (2) – (7).

## 4. RESULTS

*Scenario* 1. In the first working scenario the independent printing of each product was chosen, respectively each of

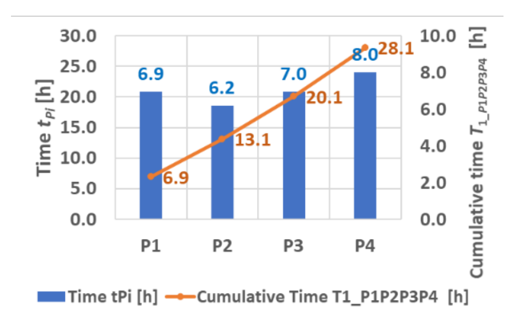


**Fig. 7.** *Scenario* 1. Run times $t_{Pi}$ for P1, P2, P3 and P4 products printed independently with machine occupancy time $T_{1\_P1P2P3P4}$= 28.1 h.

the products P1, P2, P3 and P4 consumes the time parameters at maximum values as in Table 2.

The total execution time for product P1 was calculated with Eqs. (2) – (7).

Equation (2) is applied:

$$t_{MP} = N_r \cdot t_{G1} = 4 \text{ rolls} \cdot 10 \text{ min} = 40 \text{ min}, \quad (12)$$

where from formula (1) there are $N_r$ [rolls] = 18,000 / 5,000 = 3.6 (rounded is $N_r$ = 4 rolls).

Formula (4) is applied:

$$t_T = \text{n} \cdot (t_{G3}+t_{G4}+t_{G5}) = 6 \cdot (15+5+10) = 180 \text{ min}. \quad (13)$$

Formula (5) is applied:

$$t_{RT} = (n \cdot t_{G6}) + t_{G7} = (6 \cdot 5) + 6 = 36 \text{ min}. \quad (14)$$

Product P1 is not die cut, Eq. (8) can be applied directly:

$$t_{Pi} = t_{MP} + t_T + t_{RT} + t_S + t_{RS} + t_{BT} + t_{R1} = 40 + 180 + 36 + 0 + 10 + 150 = 416 \text{ min} = 6.9 \text{ h}. \quad (15)$$

Similarly, the time values $t_{P2}$, $t_{P3}$, $t_{P4}$ are calculated for *Scenario* 1 for each of the products P2, P3, P4. The results (Fig. 7) are:

$$t_{P2} = 6.2 \text{ h}; t_{P3} = 7.0 \text{ h}; t_{P4} = 8.0 \text{ h} \quad (16)$$

and for the four independently run products P1, P2, P3, P4, the $T_1$ total occupancy time of the printing press is:

$$T_{1\_P1P2P3P4} = t_{P1}+ t_{P2} + t_{P3}+ t_{P4}= 28.1 \text{ h}. \quad (17)$$

*Scenario* 2. In the second scenario, the four products P1, P2, P3, P4 go to press successively, with all ink tanks and anilox rollers clean at START 0, and if not all tanks are used when printing a product, the remaining clean tanks are used for the next printed product and others are washed only if they are not sufficient. The anilox rollers are washed together with the tanks, and follow the same rules.

In *Scenario* 2, the 24 sequences of ordering obtained by permutations for the entry into printing of products P1, P2, P3, P4, revealed 4 groups of sequences:

- first group has 6 sequences with product P1 in the first position (Fig. 8),
- second group has 6 sequences with product P2 in the first position (Fig. 9),
- third group has 6 sequences with product P3 in the first position (Fig. 10),
- fourth group has 6 sequences with product P4 in the first position (Fig. 11).

The calculation path to be followed for each product in each series is similar to that for product P1 in *Scenario* 1, using the same Eqs. (2) – (7) and time parameters from Table 2.

## 5. ANALYSIS

Analysing the results obtained in *Scenario* 1 (Fig. 7), it was observed that each of the products P1, P2, P3 and P4 consumed maximum preparation and printing times, which varied according to the number of colours required to reproduce the graphic and whether or not it was die cut.

The lowest time of 6.2 h was consumed for P2, a single colour die cut and printed product, and at the opposite pole was P4 with a consumption of 8.0 h, a die cut product with a complex design using all the printing

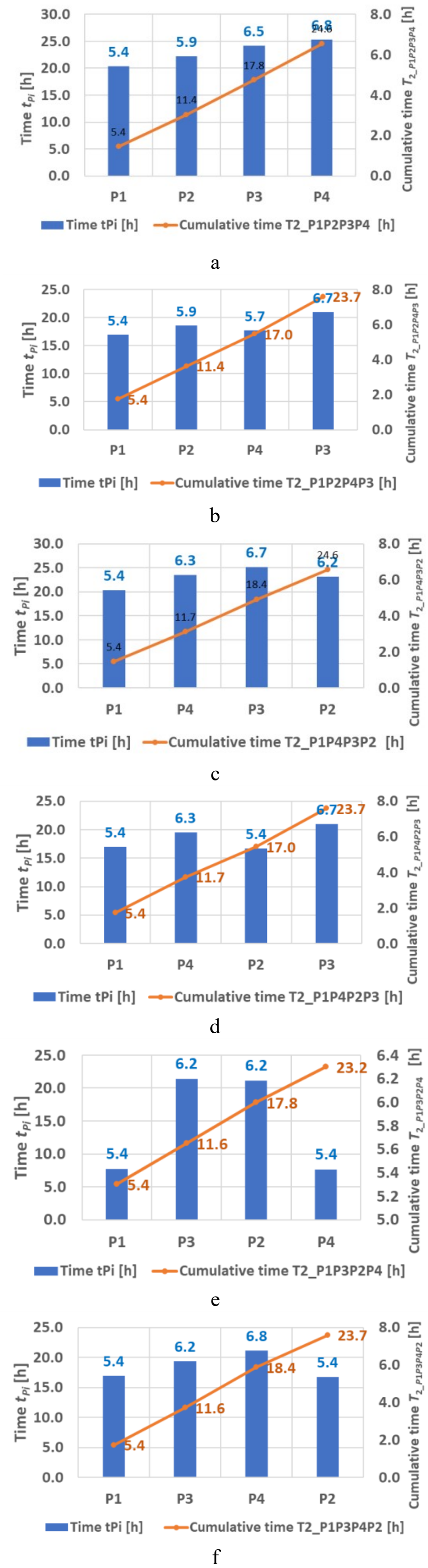


**Fig. 8.** *Scenario* 2. Execution times $t_{Pi}$ for P1, P2, P3, P4, and machine occupancy time $T_{2\_series}$ for each series in which P1 enters the production flow first: *a* – P1-P2-P3-P4; *b* – P1-P2-P4-P3; *c* – P1-P4-P3-P2; *d* – P1-P4-P2-P3; *e* – P1-P3-P2-P4; *f* – P1-P3-P4-P2.

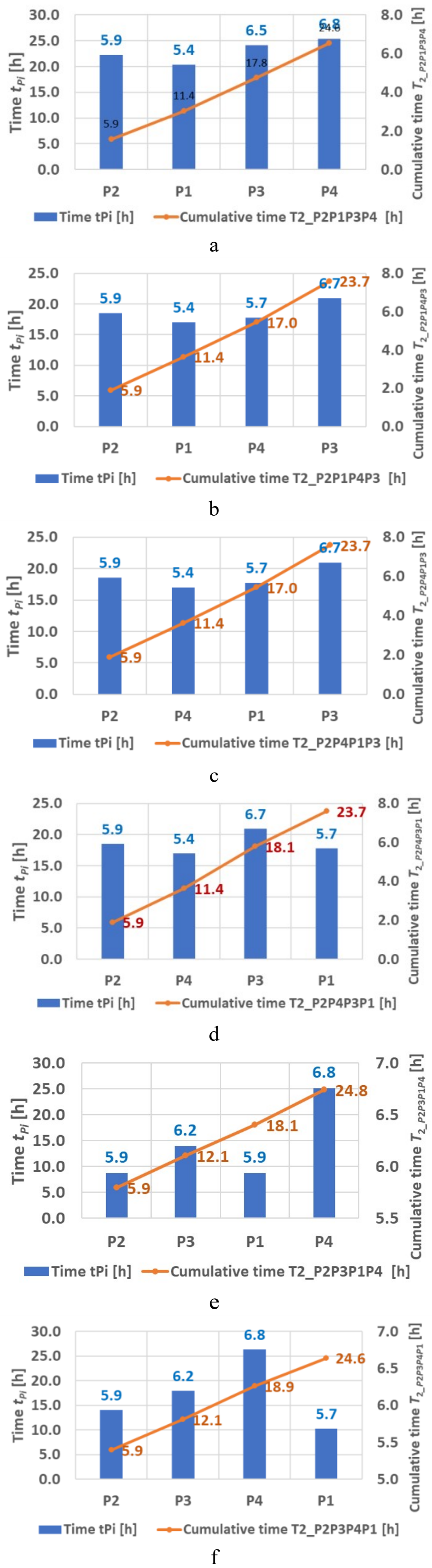


**Fig. 9.** *Scenario* 2. Execution times $t_{Pi}$ for P1, P2, P3, P4, and machine occupancy time $T_{2\_series}$ for each series in which P2 enters the production flow first: *a* – P2-P1-P3-P4; *b* – P2-P1-P4-P3; *c* – P2-P4-P1-P3; *d* – P2-P4-P3-P1; *e* – P2-P3-P1-P4; *f* – P2-P3-P4-P1.

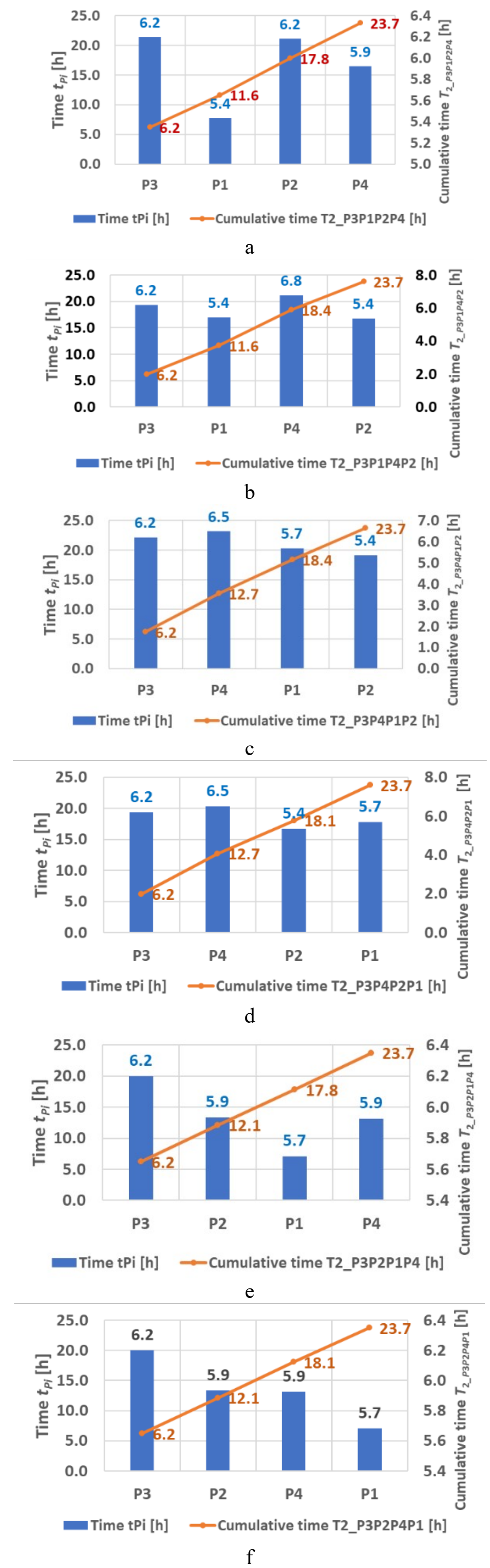


**Fig. 10.** *Scenario* 2. Execution times $t_{Pi}$ for P1, P2, P3, P4, and machine occupancy time $T_{2\_series}$ for each series in which P3 enters the production flow first: *a* – P3-P1-P2-P4; *b* – P3-P1-P4-P2; *c* – P3-P4-P1-P2; *d* – P3-P4-P2-P1; *e* – P3-P2-P1-P4; *f* – P3-P2-P4-P1.

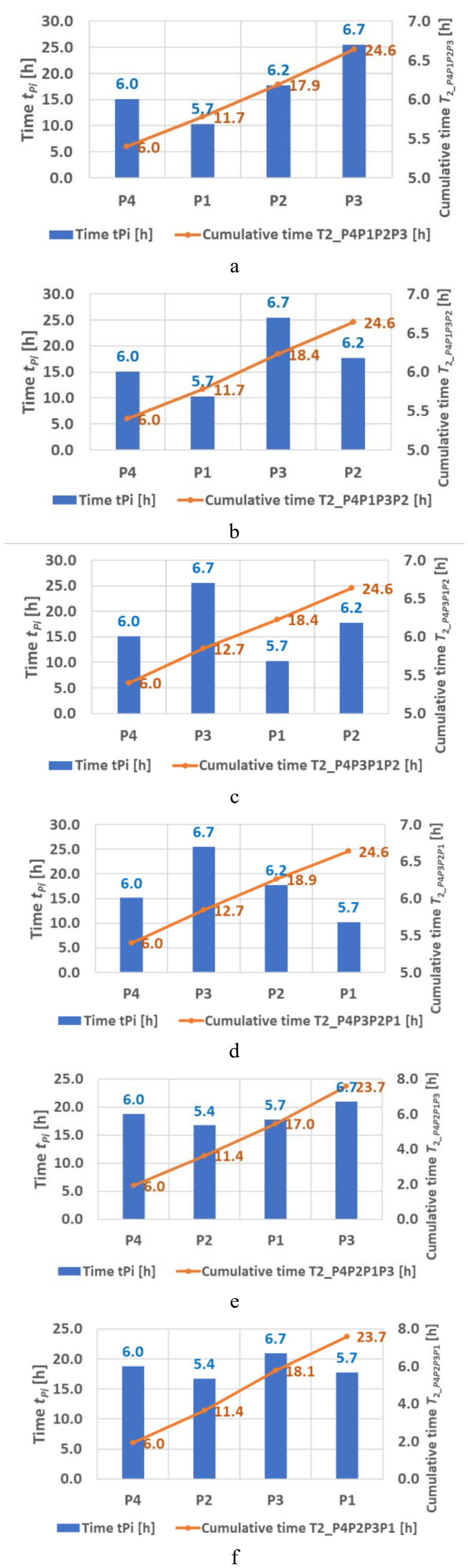


**Fig. 11.** *Scenario* 2. Execution times $t_{Pi}$ for P1, P2, P3, P4, and machine occupancy time $T_{2\_series}$ for each series in which P4 enters the production flow first: *a* – P4-P1-P2-P3; *b* – P4-P1-P3-P2; *c* – P4-P3-P1-P2; *d* – P4-P3-P2-P1; *e* – P4-P2-P1-P3; *f* – P4-P2-P3-P1.

units of the machine, having 7 colours + varnish printing, with printing on both sides of the material, which required additional time for the special routing of the material through the units.

The other two products had approximately equal consumption times, respectively P3 with 7.0 h and P1 with 6.9 h, P1 is the 5 colour printed film + varnish and P3 is the 3 colour printed and die cut sticker.

In *Scenario* 2, the analysis of the 24 sequences of sequencing obtained by permutations (Fig. 8 – 11) for the entry to printing of products P1, P2, P3, P4, revealed four values for the time $T_{2\_series}$ of machine occupancy for the production of the series, as follows: 14 series with time $T_{2\_series}$ = 23.7 h, 8 series with time $T_{2\_series}$ = 24.6 h, one series with minimum time $T_{2\_P1P3P2P4}$ = 23.4 h, and one series with maximum time $T_{2\_P2P3P1P4}$ = 24.8 h (Fig. 12).

The analysis of the results obtained in *Scenario* 2 for the 14 series with machine occupancy time $T_{2\_\text{series}}$ = 23.7 h (Fig. 12) revealed the following aspects. All these series contain sequences of P1 and P2 products using the same die cut-holder cylinder with diameter $D$ = 194.04 mm (Table 1), which means that for the second product that successively went into production, time was spent only on mounting the die cut. The series are: P1-P2-P4-P3, P1-P4-P2-P3, P1-P3-P4-P2 (Fig. 8); P2-P4-P1-P3, P2-P4-P3-P1 (Fig. 9); P3-P1-P2-P4, P3-P1-P4-P2, P3-P4-P2-P1, P3-P2-P4-P1 (Fig. 10); P4-P2-P1-P3 and P4-P2-P3-P1 (Fig. 11).

The same situation was maintained in the case of interleaving the uncut die P1 product between the other two, thus: in production, the cylinder remained in the die cutting group after the end of the run for P2 (or P4 as the case may be); P1 is foil and is not affected by the passage through the die cutting group, so after the end of the P1 run, the die cut-holder cylinder was used to mount the die cut for P4 (or P2 as the case may be). The series are P2-P1-P4-P3 (Fig. 9), P3-P4-P1-P2 and P3-P2-P1-P4 (Fig. 10).

All 6 series entering the run with P3 as the first product (Fig. 10) are included in this category of series with machine occupancy time $T_{2\_\text{series}}$ = 23.7 h regardless of the positioning of the other three products P2, P3 and P4.

Two of the six series that go into print with P4 first produced, respectively the series starting with P4-P2, belong to this category with 23.7 h machine occupancy time. P4 is front / back printed and benefits from all the printing machine's clean units, while P2 has the same die cut cylinder as P4 and requires washing only one ink unit. The series are P4-P2-P1-P3 and P4-P2-P3-P1 (Fig. 11). In the production of these series, the other two products, P1 and P3, used ink pools left over from printing P4, as follows: P1 reused Cyan, Magenta, Yellow, Black inks and P3 reused Black ink (Table 1), which led to the two series being classified in this category with $T_{2\_\text{series}}$ = 23.7 h.

Also in this category are also included three of the series that go into production with P2 first product, respectively those that group products with the common carrier cylinder at the beginning: P2-P1-P4-P3, P2-P4-P1-P3 and P2-P4-P3-P1 (Fig. 9). Basically, it is the situation analysed above but with the order of the first two products in the series reversed. The observation that

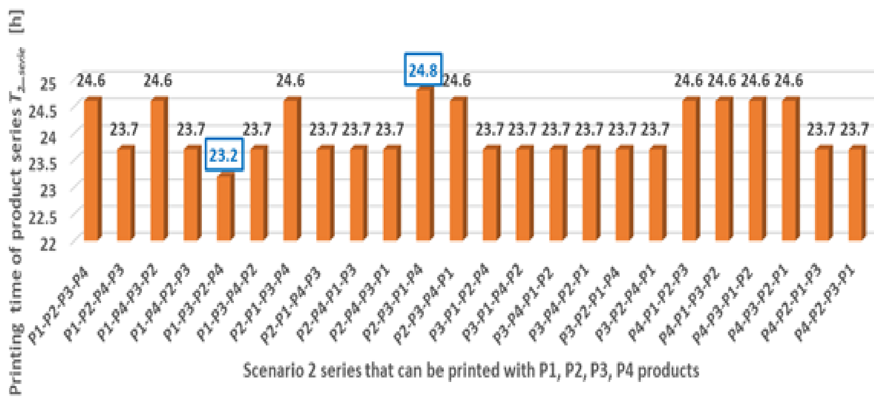


**Fig. 12.** Occupancy time $T_{2\_series}$ of the machine for the production runs of each of the 24 series obtained by permuting products P1, P2, P3 and P4.

the remaining inks from P2 and P4 are reused for printing P1 and P3 remains valid.

Three of the series entering production with P1 as the first product belongs to this category with $T_{2\_series}$ = 23.7 h, namely: P1-P2-P4-P3, P1-P4-P2-P3 and P1-P3-P4-P2 (Fig. 8). Product P1 uses 6 of the 8 groups of clean inks, and having Cyan, Magenta, Yellow, Black inks in the print, they are reused in production, in the other products. The use of the common ink-holder cylinder is also favoured for P2 and P4. It is important to note that from this category of series with P1 as the first product and an accumulation of make-ready time savings the series with the minimum total printing time will emerge.

Analysis of the following results obtained in *Scenario* 2 for the 8 series with machine occupancy time $T_{2\_series}$ = 24.6 h (Fig. 12), revealed the following aspects:

The series that go into production with P1 as the first product are those that have P2 and P4 products in positions 2 and 4 in the series, so all die cut products must have the holder cylinder fitted. The series are P1-P2-P3-P4 and P1-P4-P3-P2 (Fig. 8). Product P1 is foil and the Cyan, Magenta, Yellow, Black inks used in printing are reused in the following products in the series.

Only two of the series that enter with P2 the first product in the run belong to the category of products with a machine occupancy time of 24.6 h. The series are P2-P1-P3-P4 and P2-P3-P4-P1 (Fig. 9). Note that product P2 is the 1 colour printed TAG and the product with maximum machine occupancy time in *Scenario* 2 comes from this series group.

Here are included the other 4 series of products that go into print with P4 as the first product, respectively series P4-P1-P2-P3, P4-P1-P3-P2, P4-P3-P1-P2, P4-P3-P2-P1 (Fig. 11). P4 is the product with compex graphics, which requires by machine a special path for the material. With the exception of the P4-P1-P2-P3 series, in all other 3 series, there is no sequence in the printing of P2-P4 or P4-P2 products or with P1 sandwiched between them. This means that the joint use of the die cut-holder cylinder is not used in production.

The analysis of the series with minimum machine occupancy time of 23.4 h in *Scenario* 2 (Fig. 8), series P1-P3-P2-P4, comes from the 6 series with P1 being the first product to go to press and has the following characteristics:

- in this sequence the products consume comparable times as rounded value, thus: P1 and P4 consume 5.4 h and P3 and P2 consume 6.2 h;
- the graph is symmetrical, visually suggesting time balance;
- P4 product uses the die cut-holder cylinder fitted for the P2 product, so time is only spent fitting the die cut to the cylinder.

The maximum machine occupancy time of 24.8 h in *Scenario* 2 came from a series in the group with P2 as the first product to go to press, namely the P2-P3-P1-P4 series (Fig. 9). This is a series in which the die cut cylinder cannot be used in common because P2 and P4 are not successive products in production and the P4 compex product consumes the maximum make-ready and printing time, respectively 6.8 h.

## 6. CONCLUSIONS

From the analysis of the possible situations in the production flow in a flexographic typography, important conclusions can be drawn, as follows:

*Scenario* 1 is the one in which the products are executed independently, each product is printed by consuming a maximum setup and execution time, respectively P1 is completed in 6.9 h, P2 is completed in 6.2 h, P3 is completed in 7.0 h and P4 is completed in 8.0 h. The user occupancy time for completing all four products is 28.1 h.

*Scenario* 1 is the scenario with maximum time consumed compared to *Scenario* 2. In production this *Scenario* 1 corresponds to cases where all products required on delivery are entered into the production flow according to the FIFO strategy, and each product is printed only with special Pantone® colours, all different from each other, which require all printing units to be washed, and if stamped, all required die cut-holder cylinders have different diameters.

*Scenario* 1 also corresponds to cases where unscheduled products are introduced into the production flow initially due to the requirement to deliver the product urgently. These are a maximum time consumers of machine occupancy and sources of additional costs generator to the detriment of the benefit.

*Scenario* 2 is the scenario in which the products successively go to press, the FIFO strategy is applied, there are a total of 24 types of series obtained by permuting P1, P2, P3, P4 products and each of them goes to press first for 6 series of products.

Facilities observed in the technological flow:

P2 and P4 use the same *D* – diameter of the die cut-holder cylinder (see Table 1). This means that if the second product enters the press successively, it will not take time to change the die cut-holder cylinder.

This situation is maintained even if product P1 enters the press sandwiched between the two products P2, P4, because P1 is not die cut and the die cut-holder cylinder remains mounted in the group from the first stamped product.

For the same inks as the previous printed product, the ink tanks and anilox rollers are not washed as they can be reused.

The P4 product is consuming 8 printing units and slows down the time to complete the run by the long make-up time of the material path through the machine. Because it has the same die cut-holder roll as product P2, the entire run of 6 products in which P4 enters the press first can only generate intermediate run completion times of 23.7 h and 24.6 h respectively, both between the values of minimum 23.2 h and maximum 24.8 h.

The P3 self-adhesive label printed in 3 colours, which is the first to be printed in 6 series of products, consumes a minimum time of 6.2 h but leaves no flexibility for the rest of the products, so that all the 6 series it runs have a total run time of 23.7 h. Typical of this product is the fact that the number of special Pantone® colours it prints with is the majority in the graphics, and that the die cutting requires a die cut-holder cylinder roller.

The P2 product first in the printing, printed with 1 special colour and with the same die cut-holder cylinder as the P4 product, generates 5 series with 23.7 h and 24.6 h machine occupancy times, as well as a series with a maximum machine occupancy time of 24.8 h: this is the series in which P4 is in the last position and P1 is in the penultimate position. This type of products with one printing colour have minimum run times, generate intermediate run times but, at the same time, can generate a surprise run and a maximum machine occupancy time to run the series.

P1 with 5 colour printed foil + varnish has a set-up time without die cutting; the 6 product runs in which it goes to press first generate machine occupancy times of 23.7 h and 24.6 h, but also provide a run with minimum machine occupancy time of 23.2 h. Typical of these products is the fact that the Cyan, Magenta, Yellow, Black polychrome used in printing can be reused in printing subsequent products, if there are no special Pantone colour requirements in large numbers between the other products that would require washing these polychrome ink tanks.

The P1-P3-P2-P4 series with a minimum machine occupancy time of 23.2 h is the optimal combination of the use of all the facilities observed in production, respectively the reuse of common inks and the common die cut-holder cylinder, but also the positioning of the P4 printing unit consuming product on the last entry position in the technological flow.

Series P2-P3-P1-P4 with maximum machine occupancy time of 24.8 h, even though it has the worst ordering in the pattern, the time consumed is much less than the maximum machine occupancy time in *Scenario* 1 of 28.1 h.

Thus, it has been shown that in order to streamline typographic flows, comparative analyses are needed to apply specific strategies. In this way the best variant with the best attributes and the lowest constraints can be chosen. Also, in industrial practice, comparative analyses can support the simulation of production processes with application software support.

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